PlanetS - Project 7

Multi-faceted determination of planet properties and system architecture

Builds on existing projects, pushing them further, developing what is missing, and combining everything

The main interests in the exoplanet field reside in the detection and characterisation of solid planets, to constrain the physical and atmospheric conditions at the planet surface, and to search for possible tracers of life in their atmospheres.

Project 7 aims at consolidating and improving the first part of this enthusiastic endeavour

Project 7 (S. Udry)

Planet basic parameters and system architecture

Sub-project A (D. Ségransan) — **7.1**
Optimum combination of information

- Comparing observed and virtual planet populations
- Data and tools integration in DACE

Sub-project B (S. Udry/R. Mardling) — **7.2**
Dynamical analysis of planetary systems

- Terrestrial circumbinary planets
- Planetary system stability
- Link between planetary orbital and physical parameters

Sub-project C (S. Udry/Queloz' Successor) — **7.3**
Constraining the structure of small-mass planets

- Enabling CHEOPS science
- NGTS science operations
- PLATO

Sub-project D (D. Ségransan) — **7.4**
Extrema of regions of planetary systems

- Constraining planetary systems with GAIA
- SPHERE optimum reduction pipeline
- Statistical analysis of direct imaging surveys

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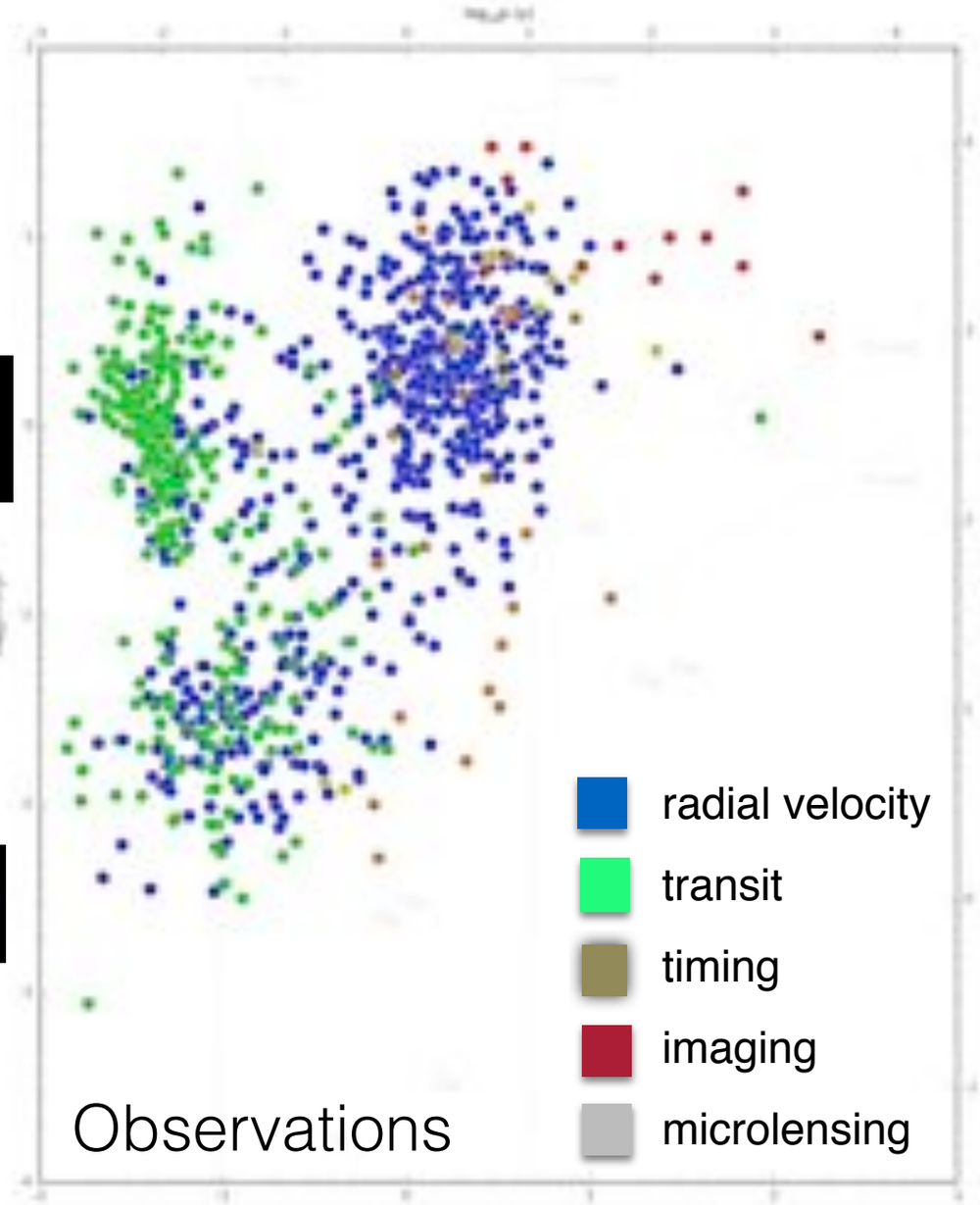
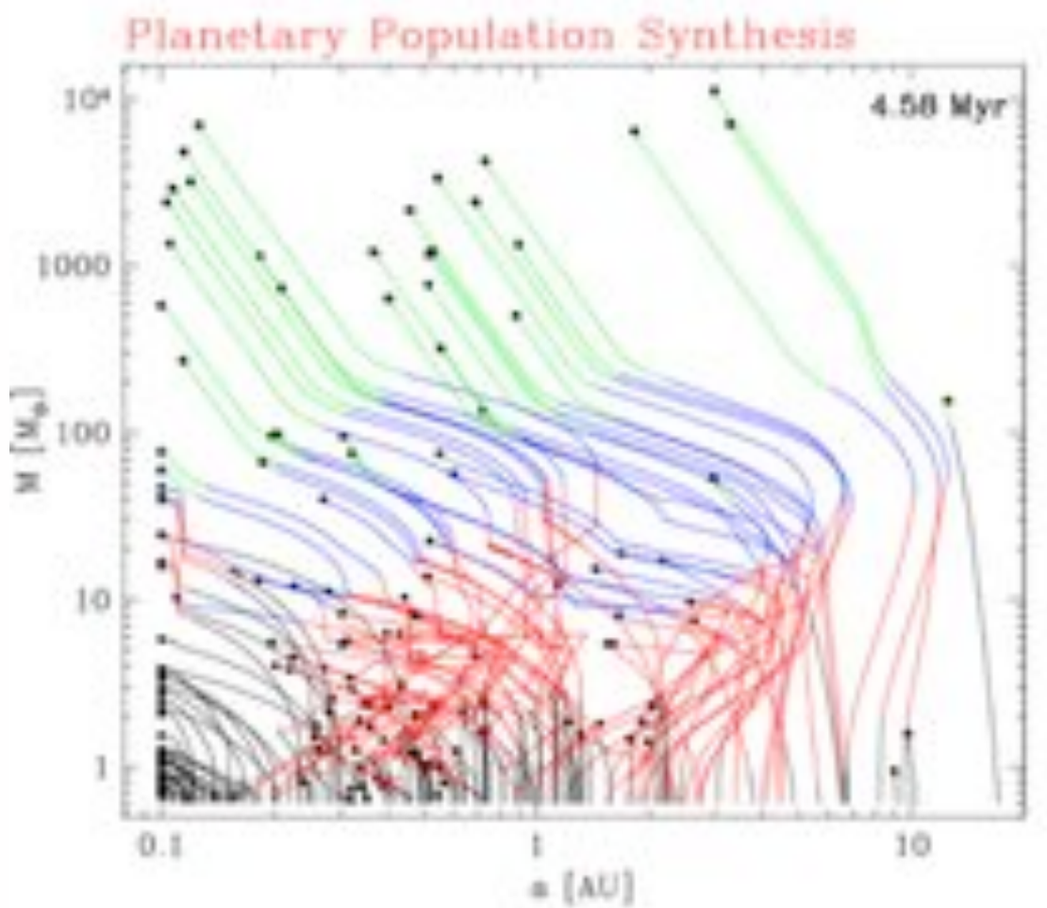
Planet fundamental physical parameters

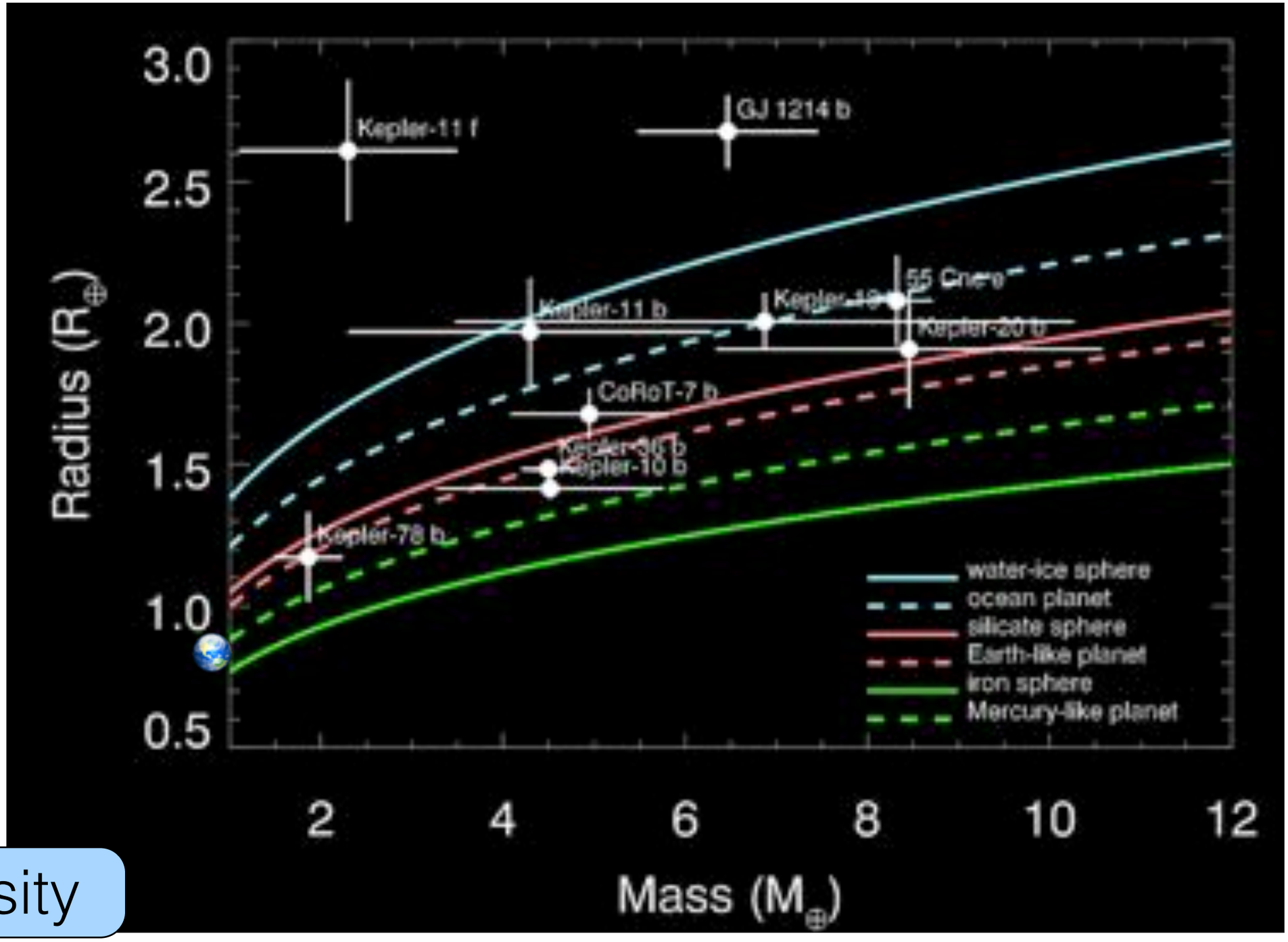
Mass





Formation models (Project 5)

Mass-radius relations



Diversity

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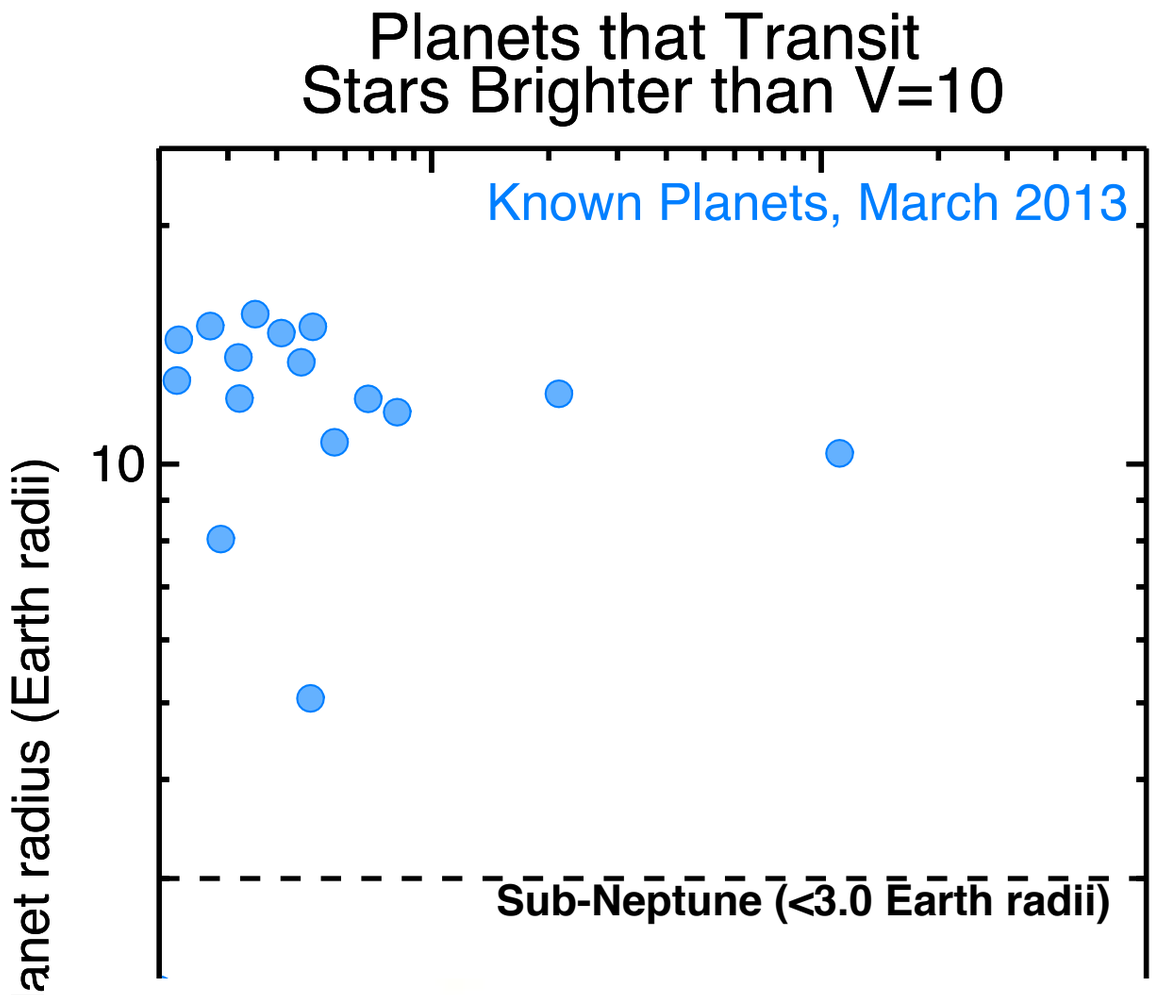
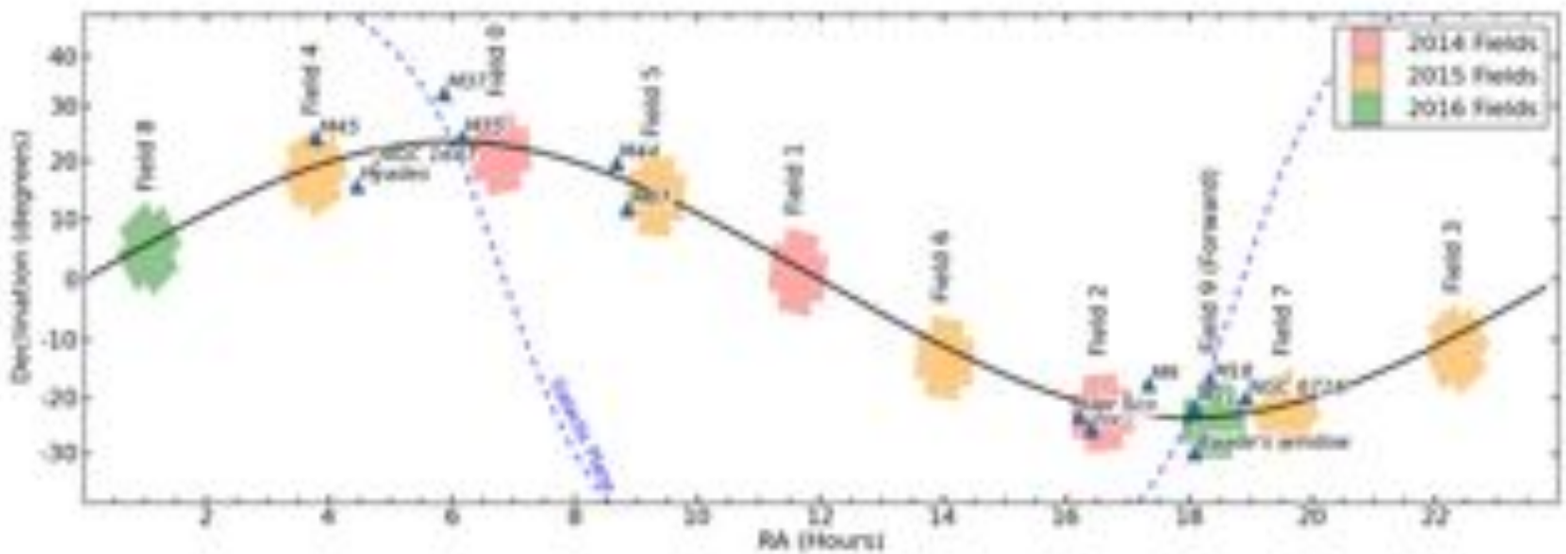
Lack of transiting planets around bright stars



Satellites targeting bright stars

CHEOPS
2017

TESS
2017



PLATO
2024

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Next Generation Transit Search (NGTS) commissioning 06.2014 - 03.2015

Talk by Dan Bayliss

- Consortium:

Geneva/CH - Warwick/UK - Leicester/UK - Belfast/UK - DLR/D - Cambridge/UK, Catolica/Chile

- 12x20 cm telescopes
- 12x8 square degrees FoV
- ~ 1 mmag precision
- to smaller stars (K and early M types)
- 2015

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Project 7 *Multi-faceted determination of planet properties and system architecture*

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Sub-Project 7.2 *Constraints from dynamical modeling of planetary systems*

Sub-Project 7.3 ***Constraining the structure of small mass planets***

Sub-Project 7.4 *Probing the outer regions of planetary systems*

Swiss National Science Foundation

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NCCR

Sub-project 7.3

(S. Udry/Queloz' Successor)

Constraining the structure of small-mass planets

S. Udry

Self-group

CHEOPS consortium

PhD calibration CHEOPS PhD

Position opening now

Enabling CHEOPS science

D. Queloz

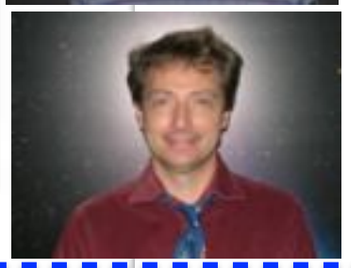
D. Ehrenreich

C. Lovis

B. Chazelas

D. Bayliss / postdoc

NGTS science operations



F. Bouchy

snf

M. Neveu / PhD

NGTS consortium

S. Saesen / SO

R. Diaz / postdoc

PLATO

PLATO consortium

Mass

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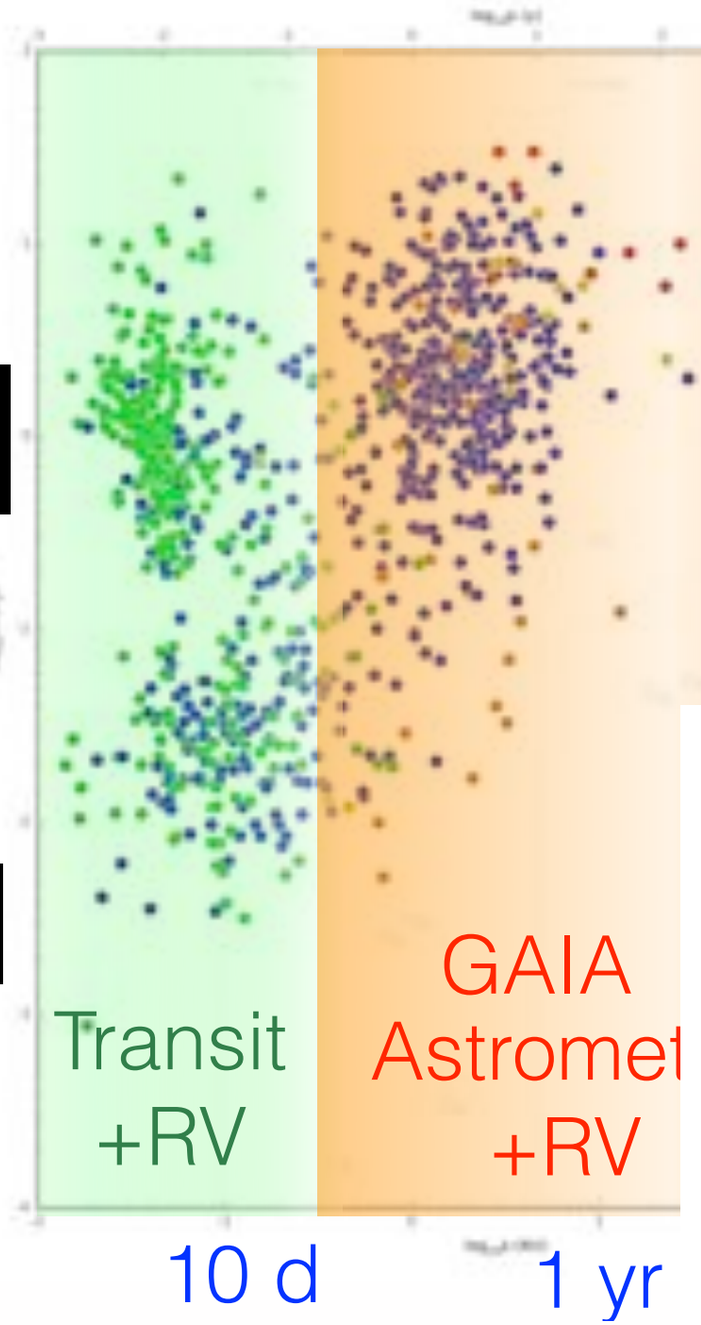
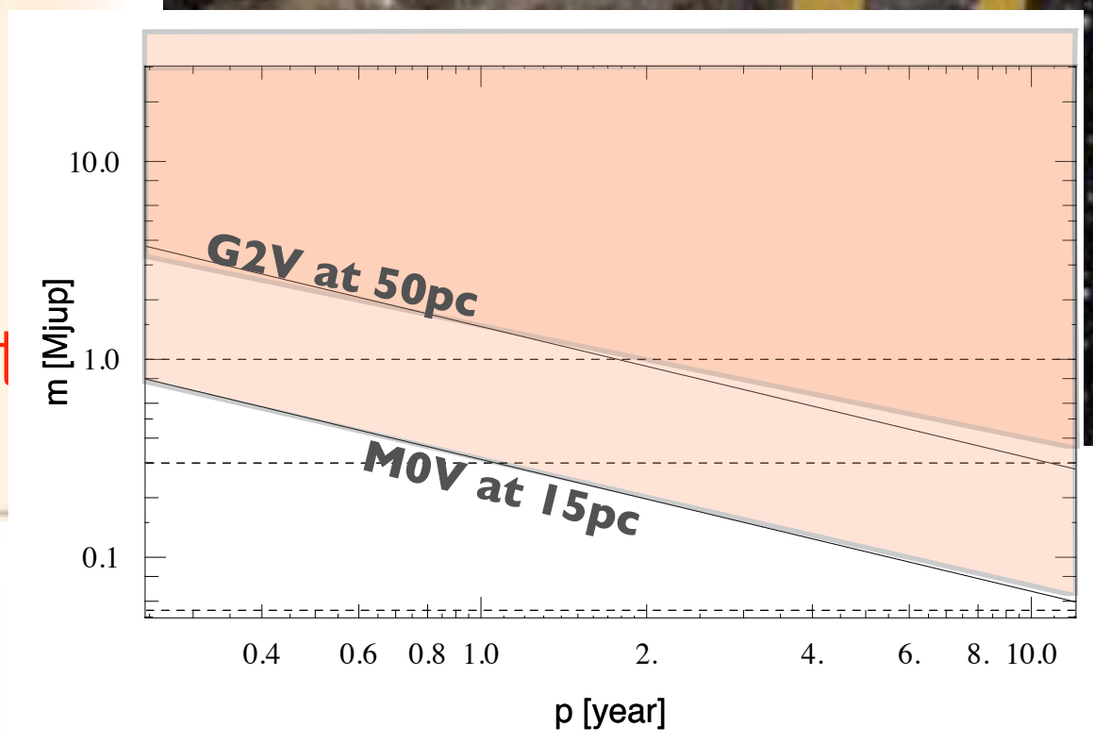
PlanetS
National Centre of Competence in Research

Census of giant planets between 1 and 7 AU around bright stars





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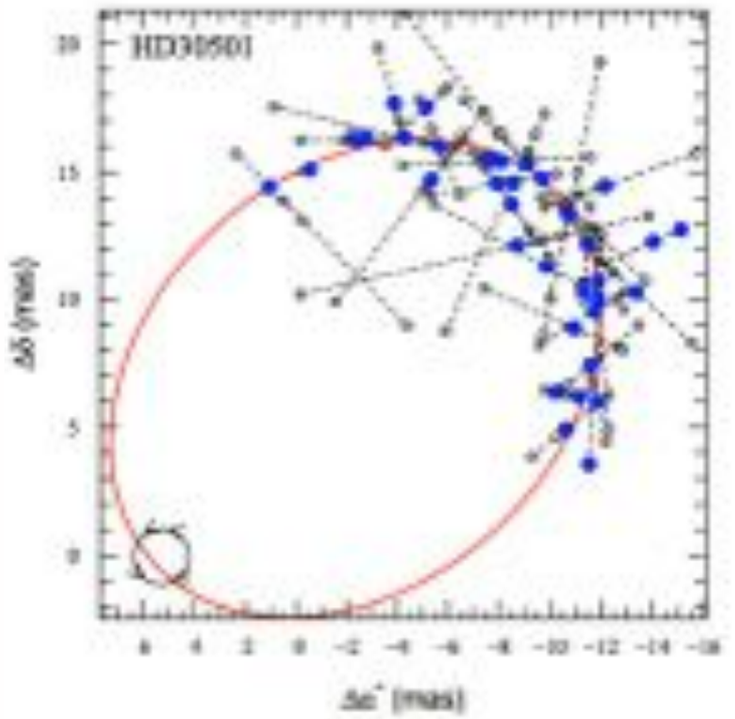
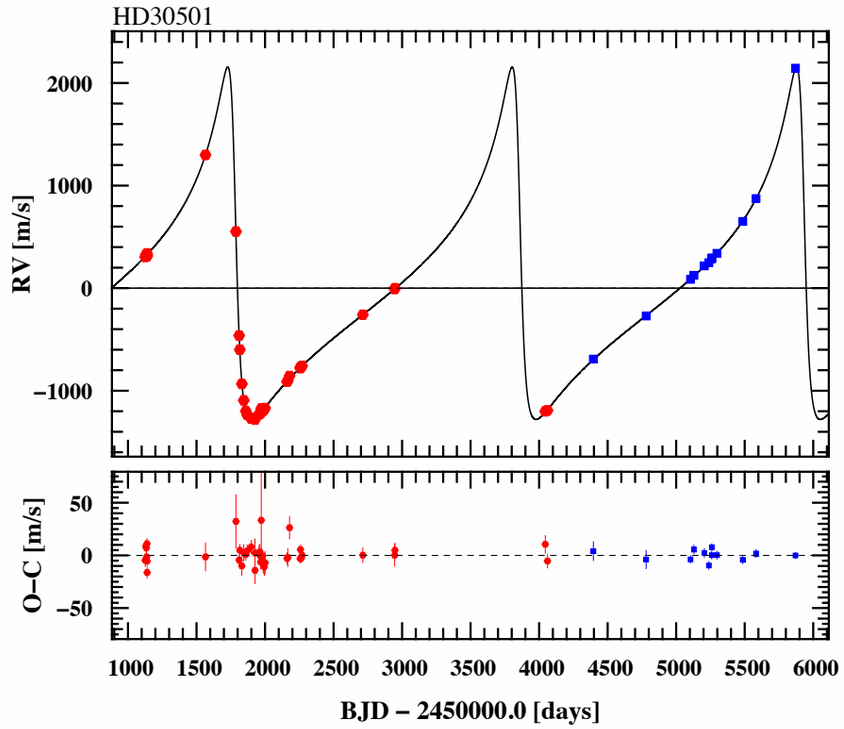
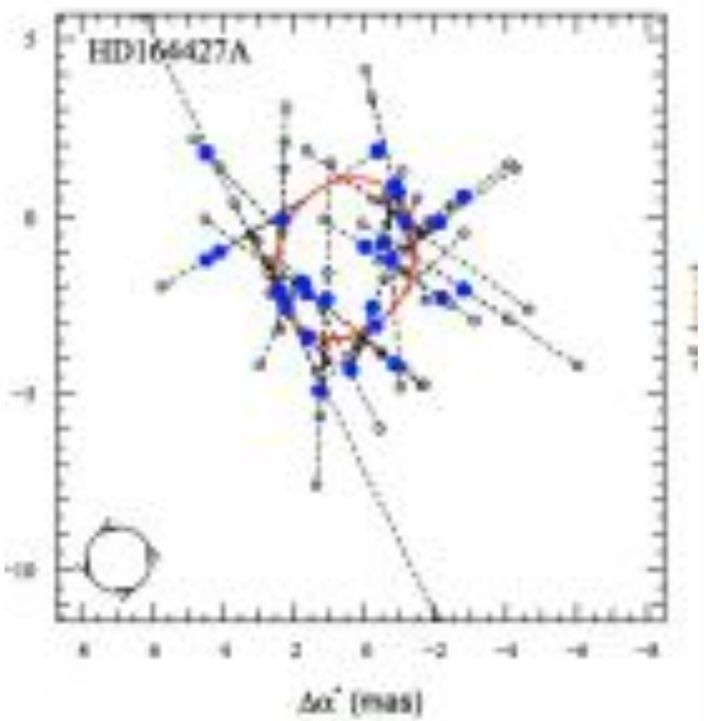
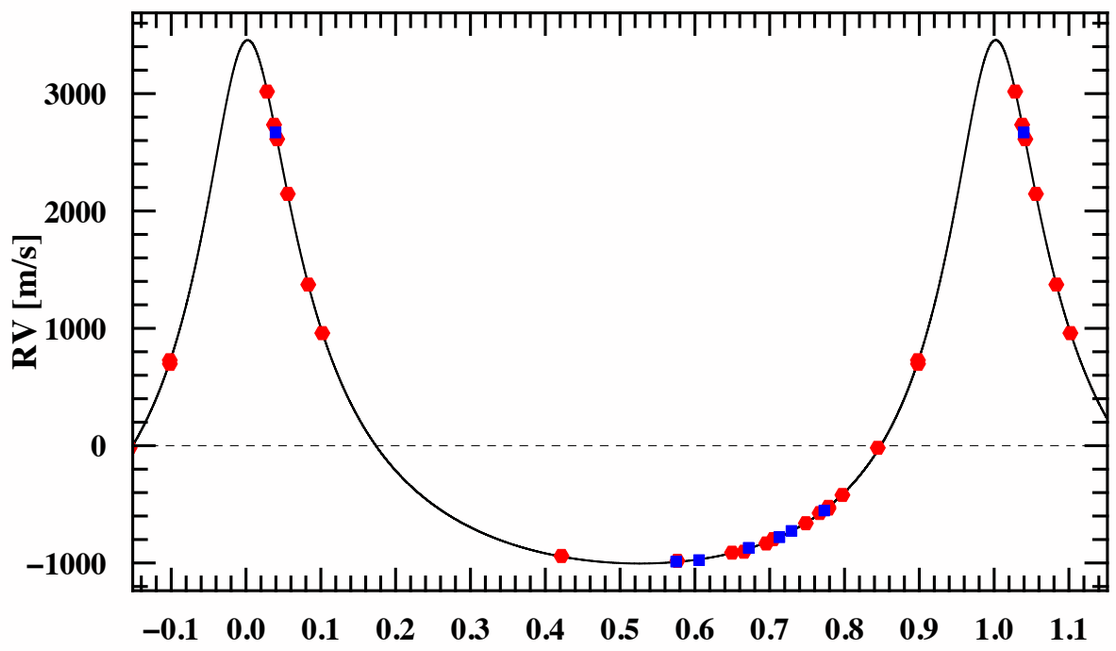
Coralie RVs + Hipparcos astrometry





$M_2 \sin i$ = 62.3 +/- 2 Mjup
M_2=89.6 Mjup





M = 46 +/- 1.6 Mjup
M_2=0.27 M_{Sun}

Sahlmann, Ségransan et al., 2011

Giant planets beyond a few AUs

Mass

Transit
+RV

Gaia
Astrometry
+RV

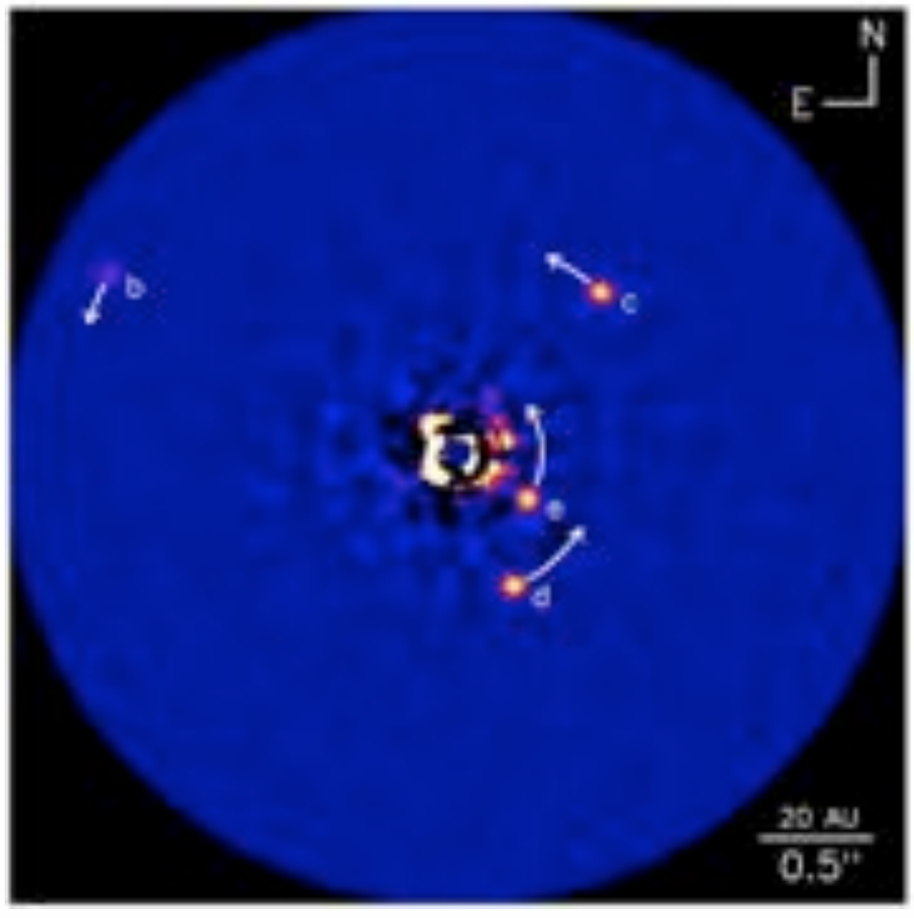
SPHERE/VLT
Direct imaging

10 d

1 yr

Period

HR 8799



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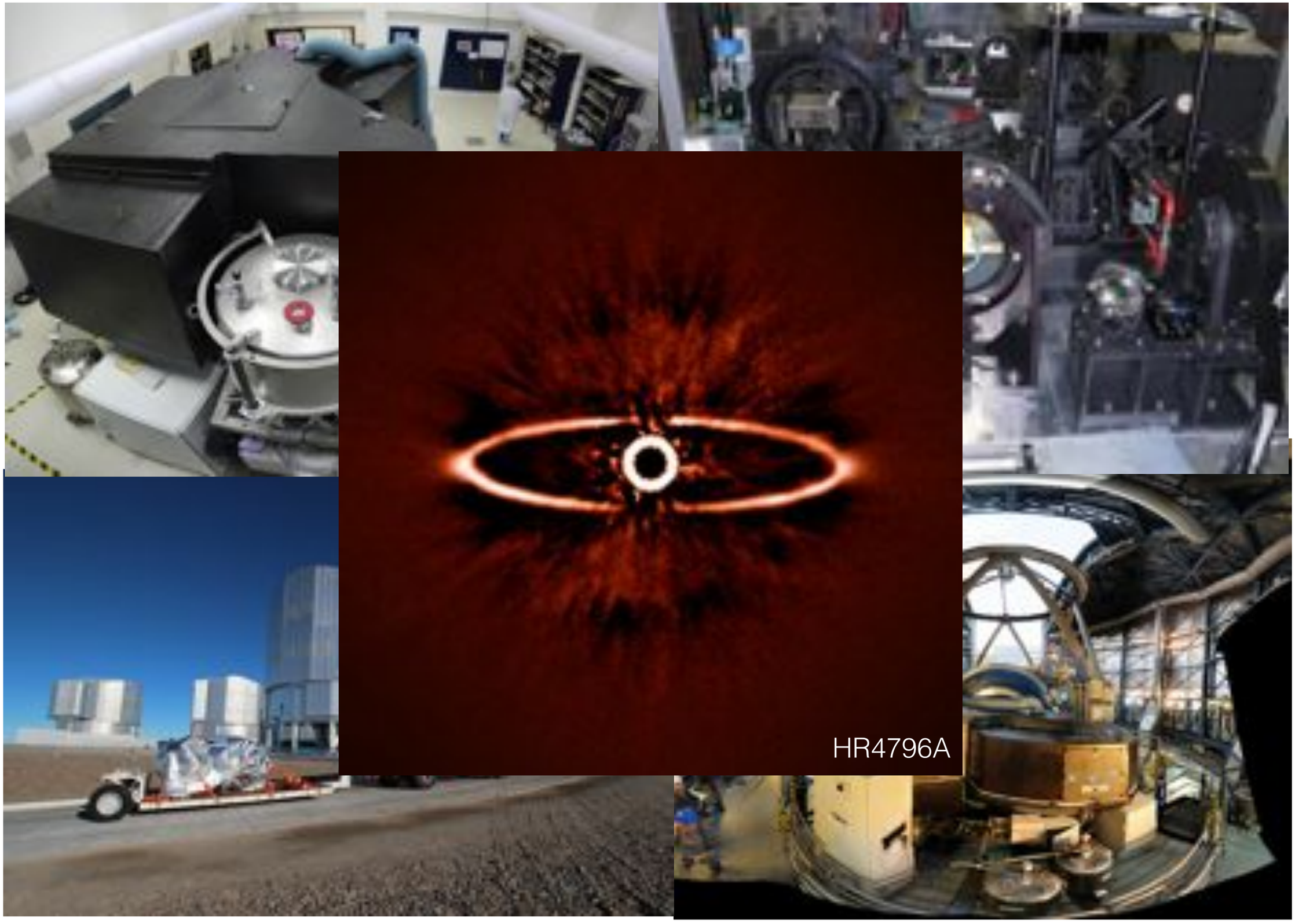
SPHERE, VLT planet imager



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Project 7 *Multi-faceted determination of planet properties and system architecture*

Sub-Project 7.1 *Optimal determination of planetary physical and orbital parameters*

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Sub-Project 7.4 ***Probing the outer regions of planetary systems***

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NCCR

M. Raimbault / PhD

A. Cheetham / potdoc
Start: April 2015

Sub-project 7.4

(D. Ségransan)

External regions of planetary systems

Constraining planetary systems with GAIA

SPHERE optimum reduction pipeline

Statistical analysis of direct imaging surveys

Project 1
ETHZ

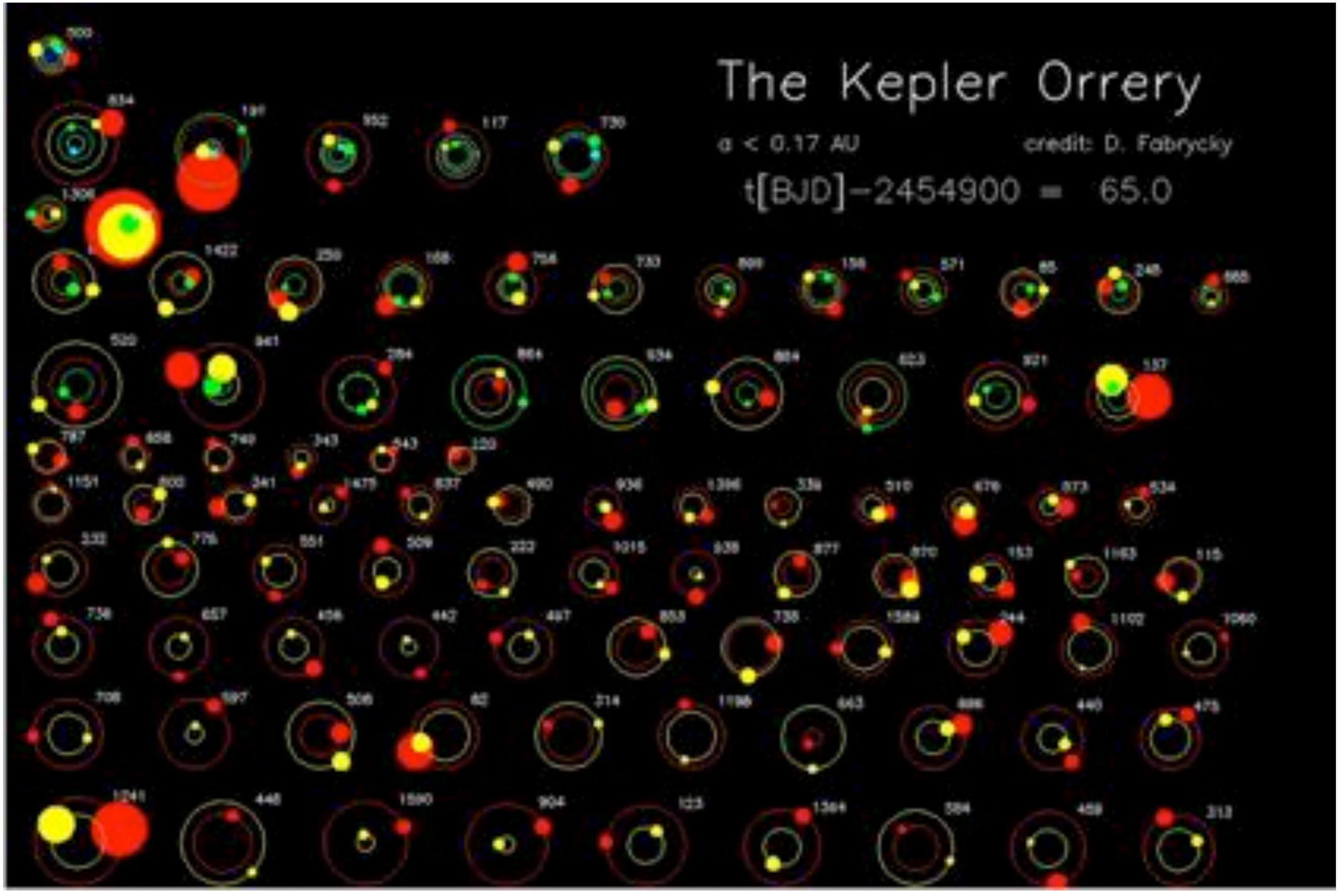
D. Ségransan

Self

snf

S. Perretti / PhD

Planetary systems



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HD10180
7-planet system

P_1 = 1.18 day
e_1 = 0
m_1 sini = 1.5 $M_\oplus$

P_2 = 5.76 days
e_2 = 0.07
m_2 sini = 13.2 $M_\oplus$

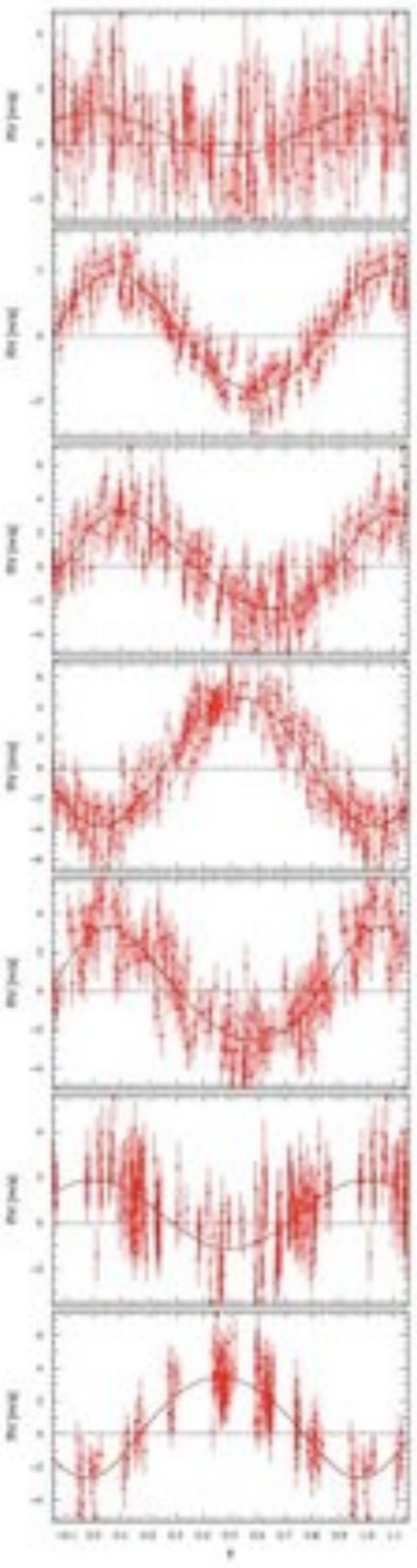
P_3 = 16.4 days
e_3 = 0.16
m_3 sini = 11.8 $M_\oplus$

P_4 = 49.7 days
e_4 = 0.06
m_4 sini = 24.8 $M_\oplus$

P_5 = 122.7 days
e_5 = 0.13
m_5 sini = 23.4 $M_\oplus$

P_6 = 595 days
e_6 = 0.0
m_6 sini = 22 $M_\oplus$

P_7 = 2150 days
e_7 = 0.15
m_7 sini = 67 $M_\oplus$



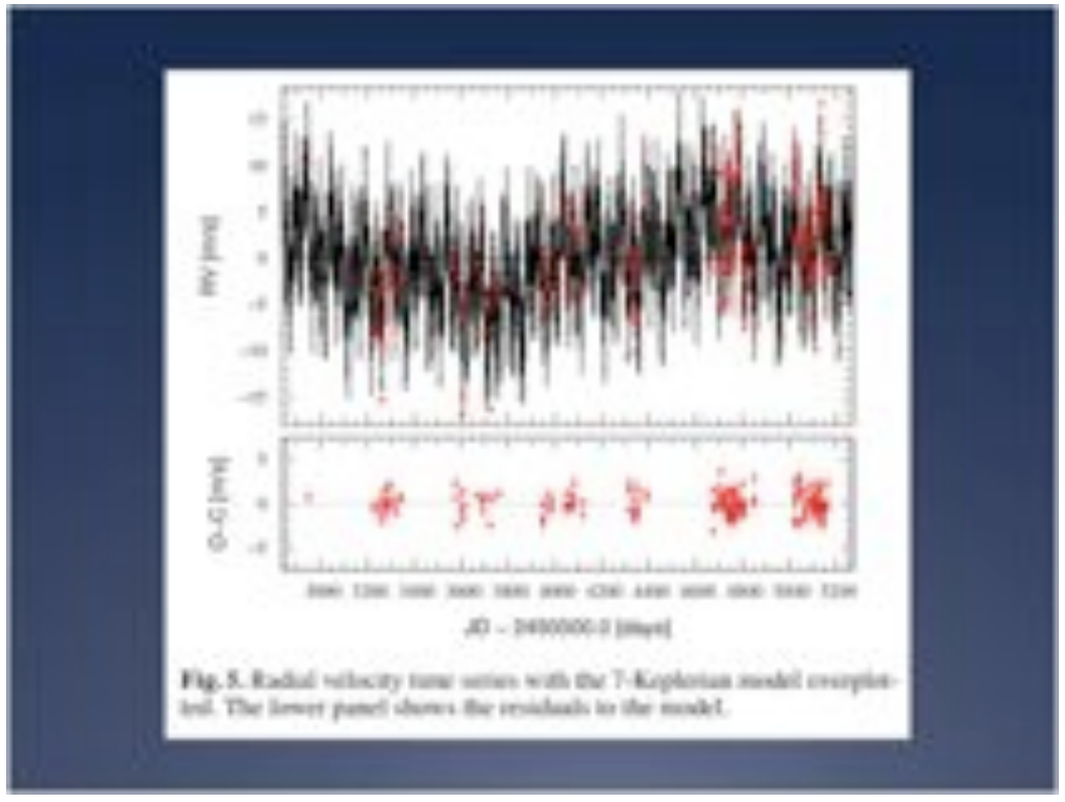
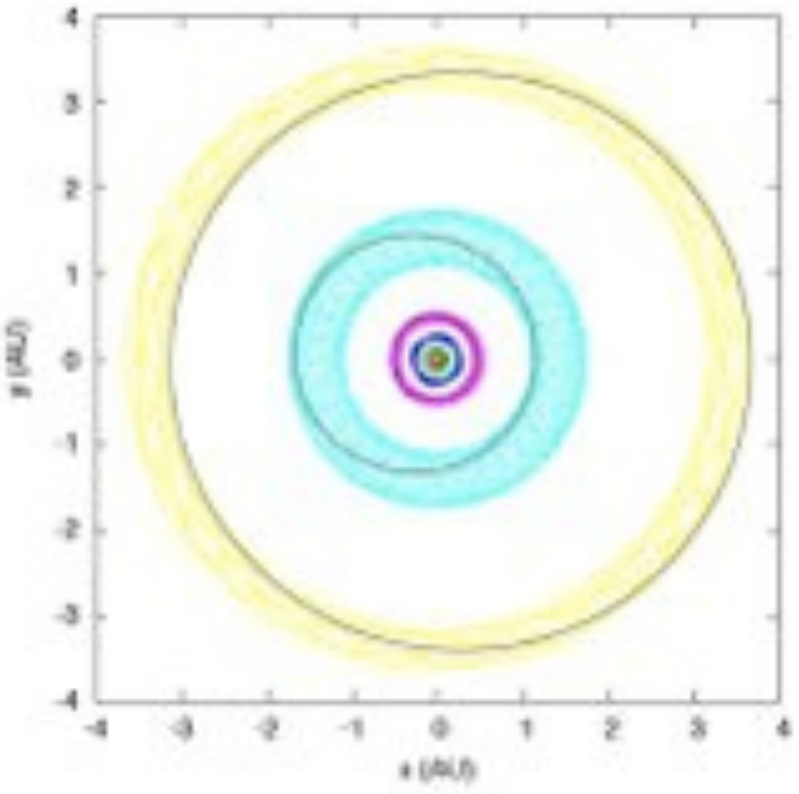


Fig. 5. Radial velocity time series with the 7-Keplerian model overplotted. The lower panel shows the residuals to the model.

Lovis, Segransan, Udry, Mayor et al. 2010



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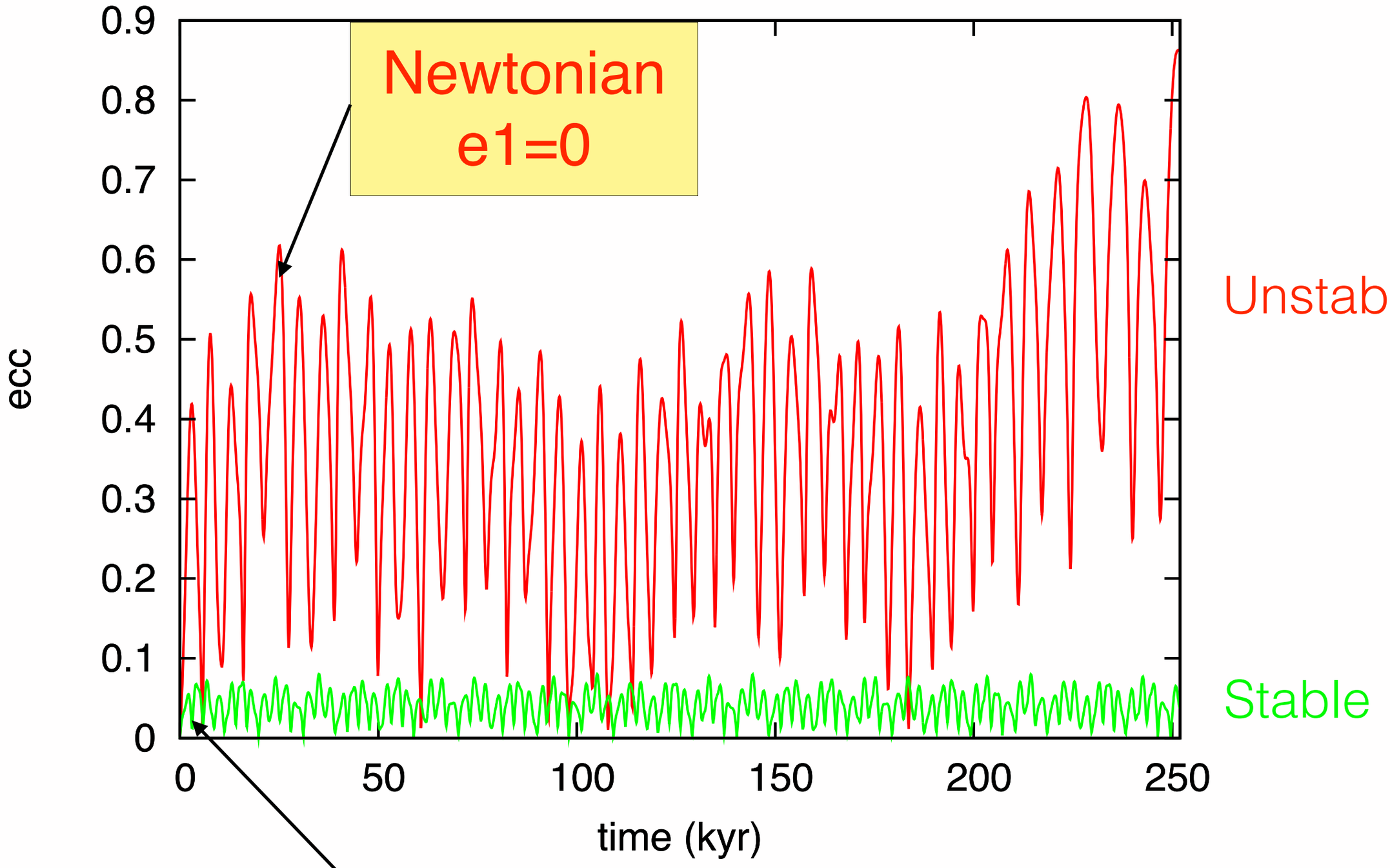
HD10180 eccentricity evolution



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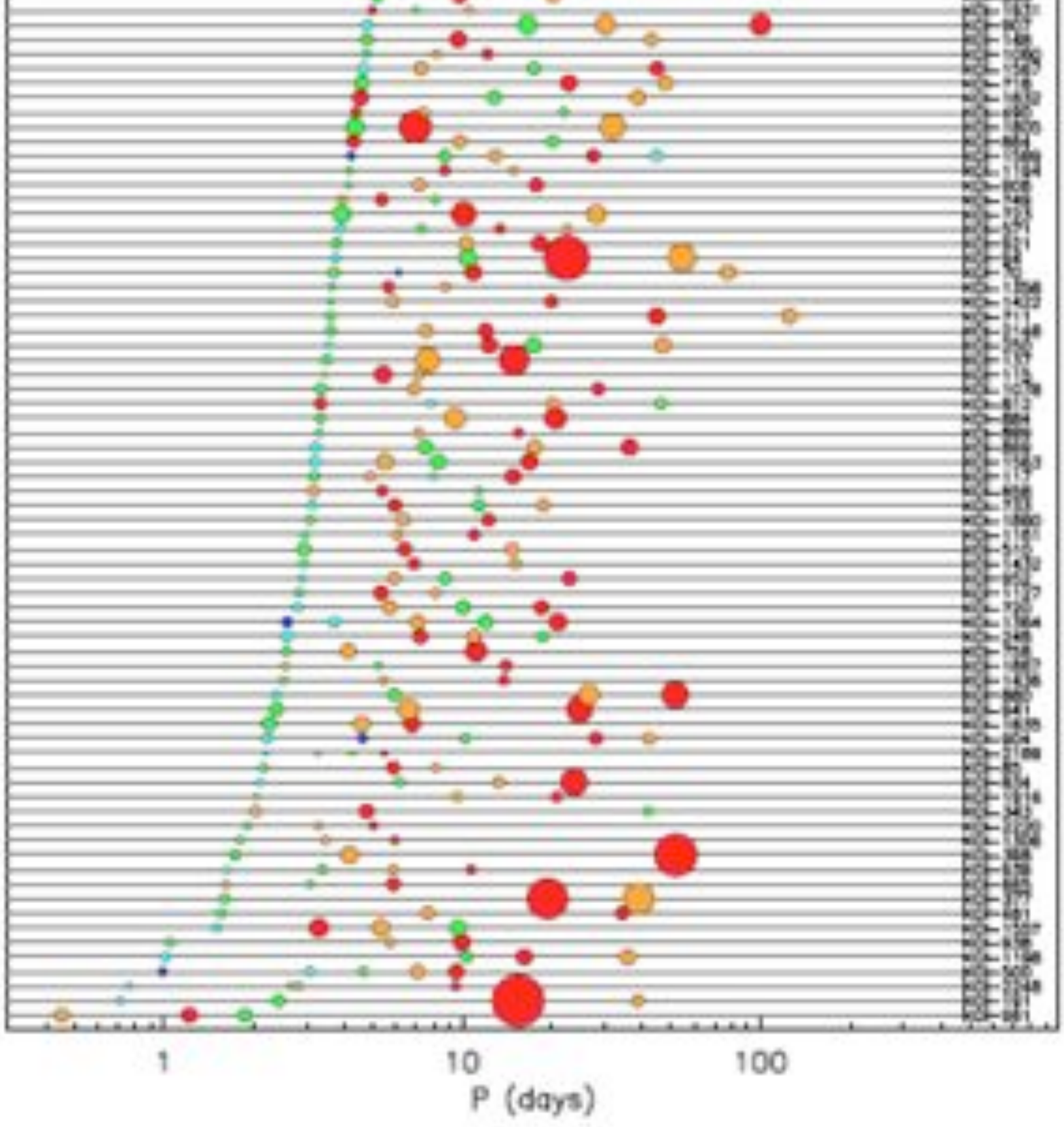

Kepler multi-transiting systems

>700 systems

similar properties for
RV & Kepler systems
(several 100s)

The systems are very coplanar

The size is known
rather than the mass

> 120 systems with TTV
(Transit Timing Variation)
some => masses

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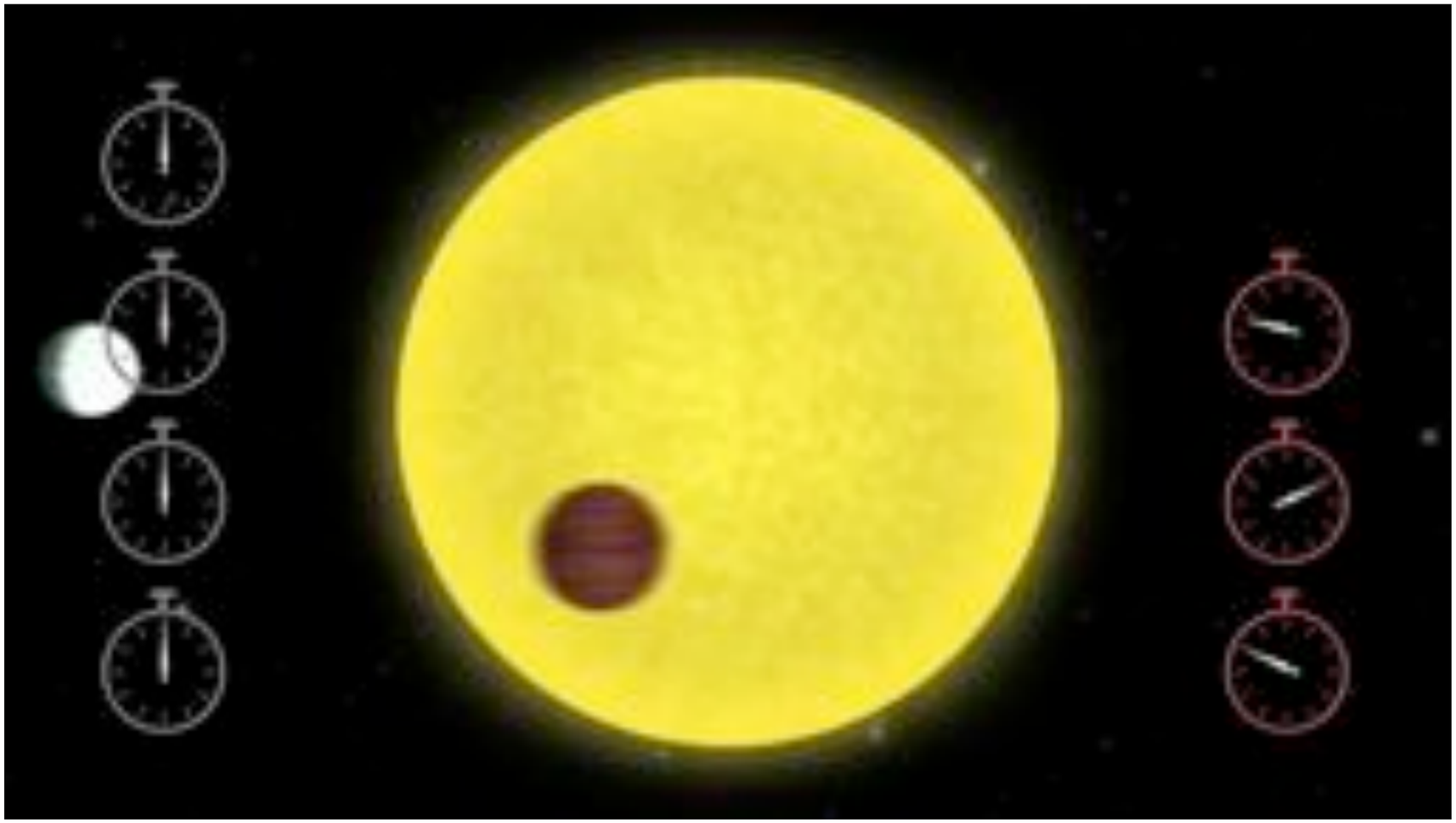
Transit timing Variations

(Credit: NASA Ames Research Center/Kepler Mission)



Observed for

- multi-planet systems
- planets with moons
- circum-binary planets

Transit timing variations due to additional companion

- keplerian motion
- planet-planet interactions
- apsidal advance, ...
- light travel time

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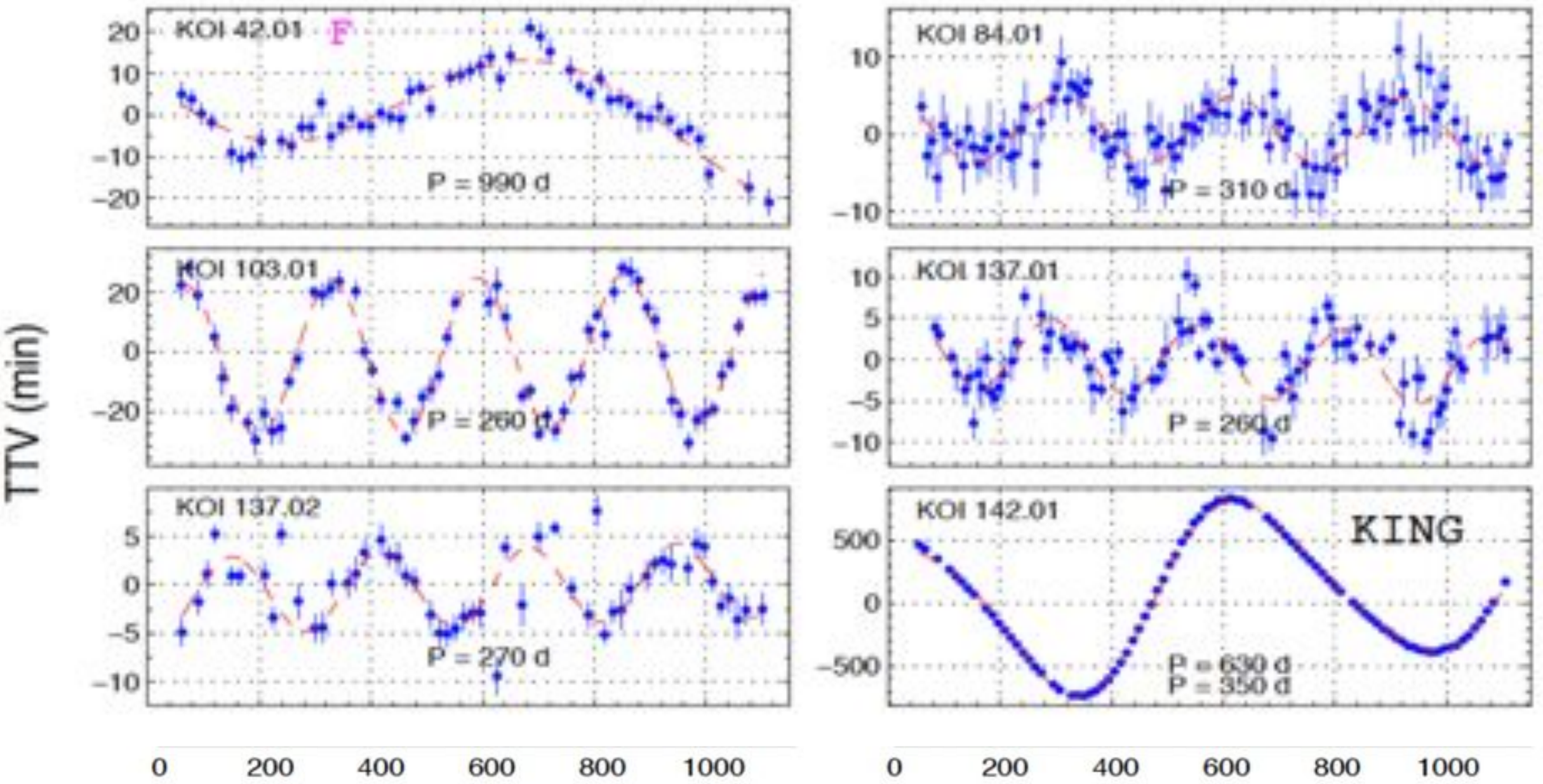
Kepler TTVs (several hundreds)



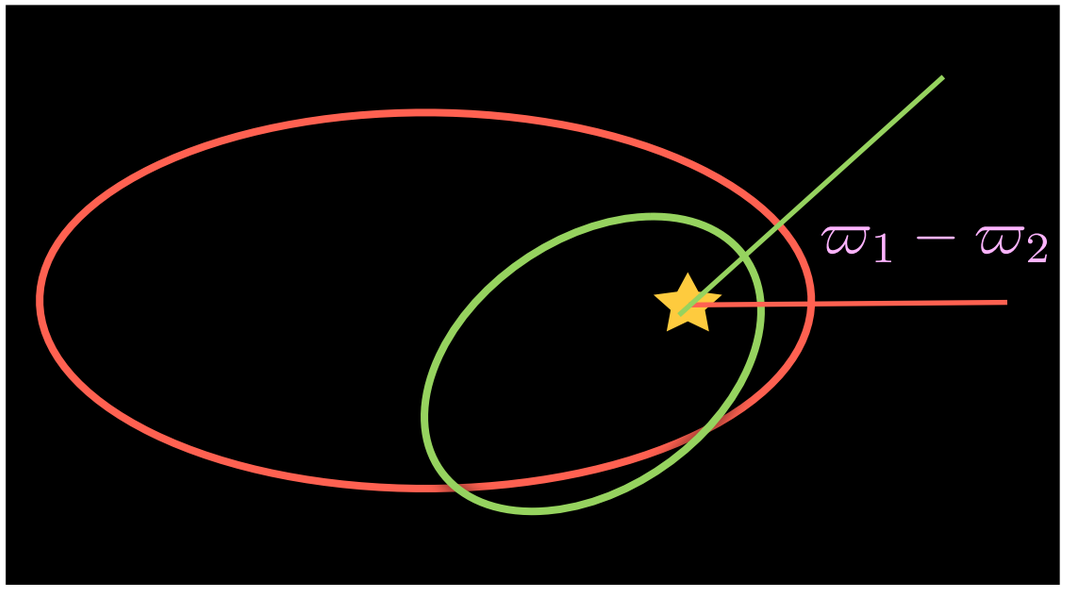
Mazeh et al 2012

Celestial mechanics for coplanar 2-planet systems

$$E_{\rm total} = E_1 + E_2 + \mathcal{R}$$

$$E_1 = -\frac{Gm_1m_*}{2a_1}, \quad E_2 = -\frac{Gm_2m_*}{2a_2}$$

1. The `disturbing function' $\mathscr{R}$ is responsible for moving energy and angular momentum between the orbits



2. Three distinct frequencies:
   + two orbital frequencies (M_1 and M_2)
   + difference in apsidal motion frequencies
   => expand $\mathscr{R}$ in triple Fourier series

$$\mathcal{R} = \sum_{mnn'} f(m_1/m_*, m_2/m_*, a_2/a_1, e_1, e_2) \cos\phi_{mnn'}$$

3. Harmonic angle is a linear combination of all angles. It can circulate or librate Resonance

$$\phi_{mnn'} = nM_1 - n'M_2 + m(\varpi_1 - \varpi_2)$$

Importance of analytical modeling

$$E_{\rm total} = E_1 + E_2 + \mathcal{R}$$

$$\mathcal{R} = \sum_{mnn'} f(m_1/m_*, m_2/m_*, a_2/a_1, e_1, e_2) \cos \phi_{mnn'}$$

$$E_1 = -\frac{Gm_1 m_*}{2a_1}, \quad E_2 = -\frac{Gm_2 m_*}{2a_2}$$

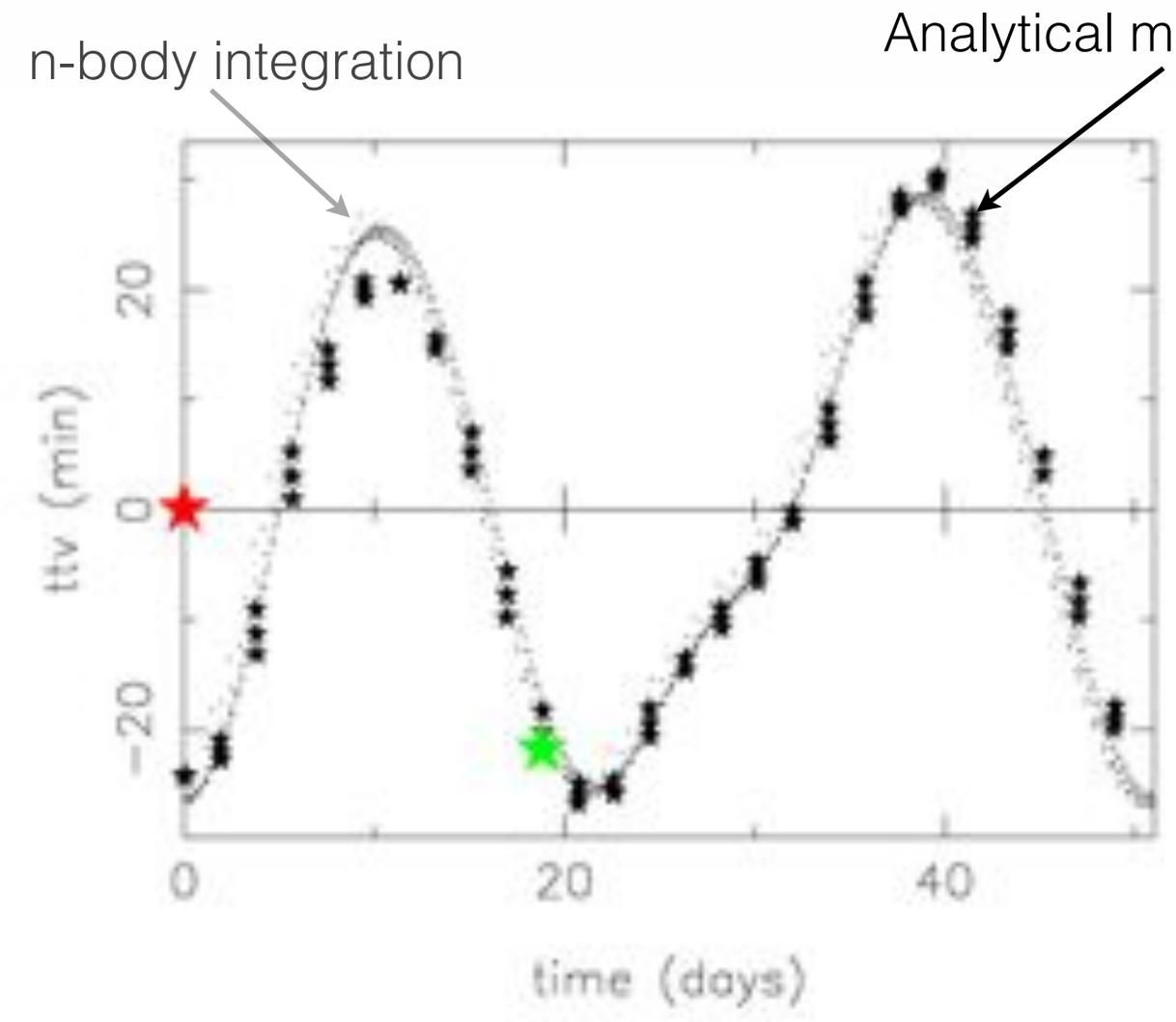
$$\phi_{mnn'} = nM_1 - n'M_2 + m(\varpi_1 - \varpi_2)$$

1. quicker, if number of considered terms are tractable

2. Simplifications (separate the contribution)
   - use of “only” the relevant terms (resonant, secular)

3. explicit dependance between the various parameters
   - we “understand” what is happening

TTV analytical approach
(Mardling in prep)



Solution: 2 key (smart) aspects

1. handle the “Fourier series” (far from resonance)
2. use a mapping approach to jump from 1 transit to the next (no orbit integration)

=> hundred times faster than any numerical integration of the orbit

=> hundred of systems still unresolved

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NCCR

R. Mardling (Co-lead)

Sub-project 7.2

(S. Udry/R. Mardling)

Dynamical analysis of planetary systems

S. Udry

Self

Terrestrial circumbinary planets

D. Martin/ PhD

snf

Planetary system stability

Project 6, UniZH

Link between planetary orbital and physical parameters

J-B Delisle / postdoc

Talk by Jean-Baptiste

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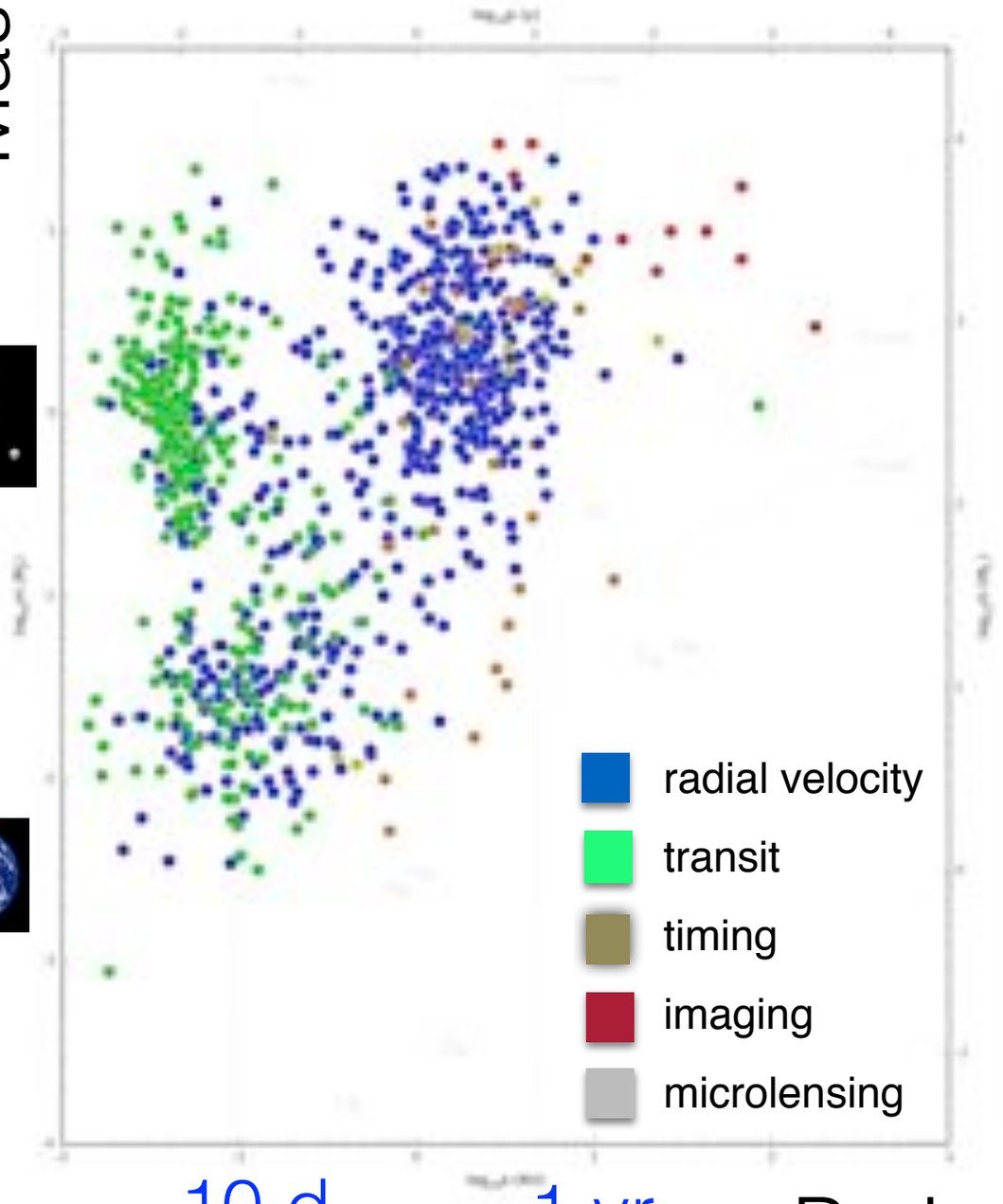
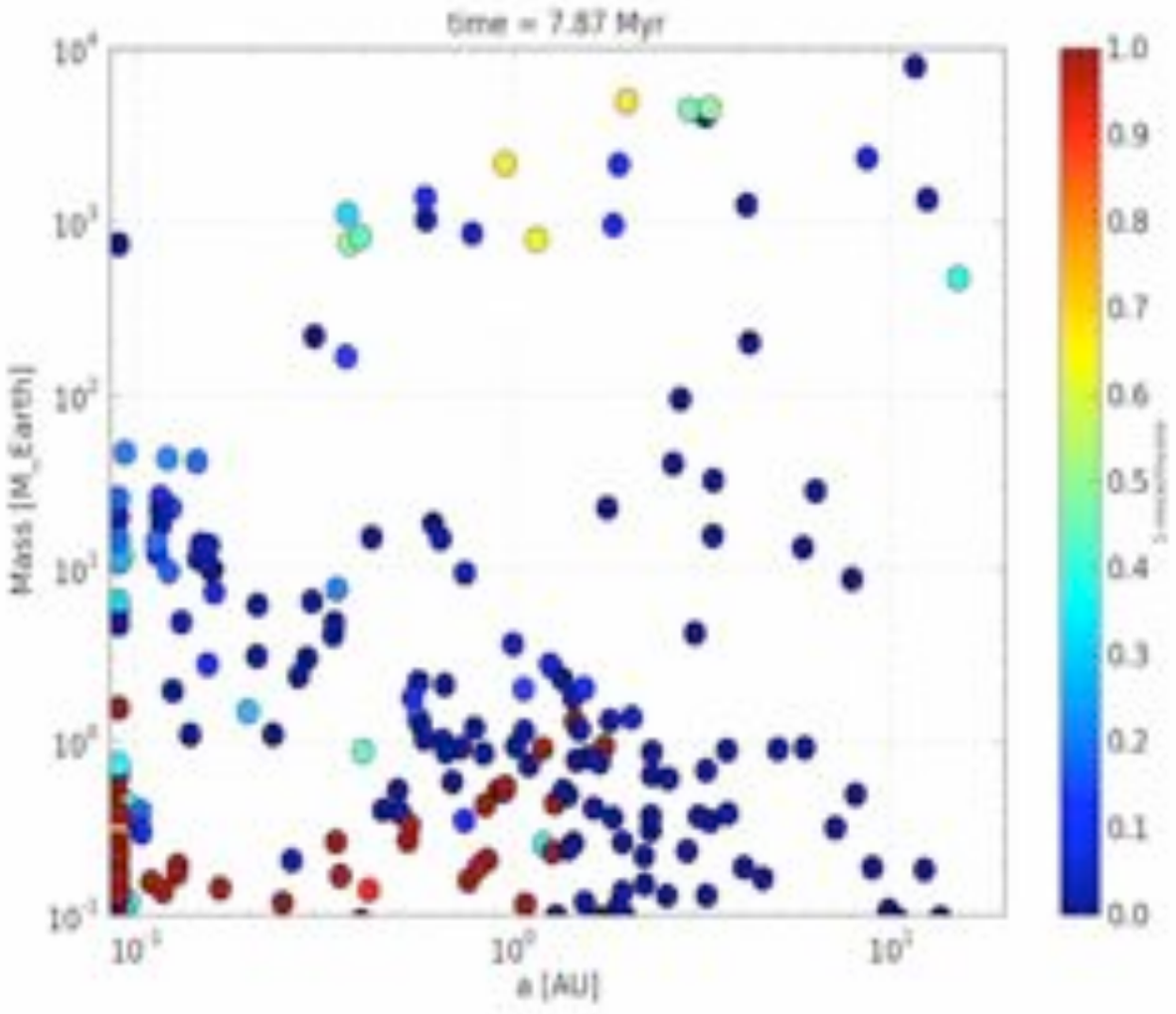
Properties of planets in multiple systems taking into account all aspects: observations + theoretical constraints

In the future: time/age axis as well

Mass



10 d 1 yr Period



Formation models (Project 5)

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NCCR

Project 5, UniBE

Thibaut Roger / PhD

co-supervision 5.1+7.1

Sub-project 7.1

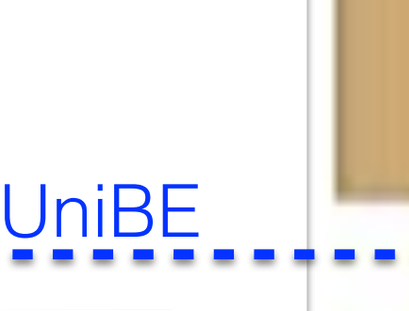
(D. Ségransan)

Optimum combination of information

Comparing observed and virtual planet populations

Data and tools integration in DACE

D. Sosnowska



R. Diaz

Talk by Rodrigo Diaz

Self

D. Ségransan

other

M. Marmier

J. Rey

The Project-7 task force

Project 3

Planet basic parameters and system architecture

Project 5, DACE

(D. Ségransan)
Optimum combination
of information

Project 6

(S. Udry/R. Mardling)
Dynamical analysis
planetary systems

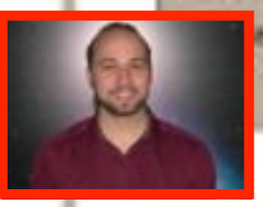
CHEOPS

(S. Udry/Queloz' Successor)
Constraining the structure
of small-mass planets

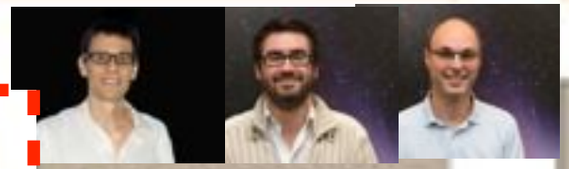
Project 1

(D. Ségransan)
Extrasolar regions
of planetary systems

Comparing
observed and virtual planet
populations

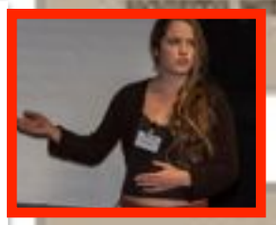


Terrestrial circumbinary
planets



Enabling CHEOPS science

Constraining planetary
systems with GAIA



Data and tools
integration in DACE

Planetary system stability

NGTS science operations

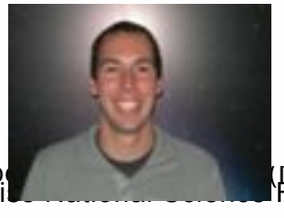
SPHERE
optimum reduction pip

ink between planetary
orbital and physical
parameters

PLATO

Statistical analysis of
direct imaging surveys

PhD: snf-other



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